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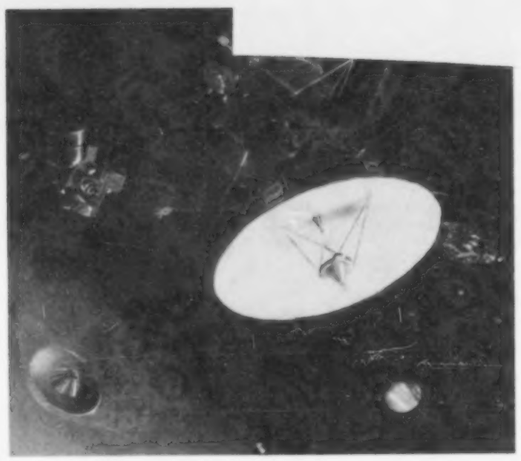
Outward to the Beginning, T...

OUTWARD TO THE BEGINNING

The CRAF
and
Cassini
Missions



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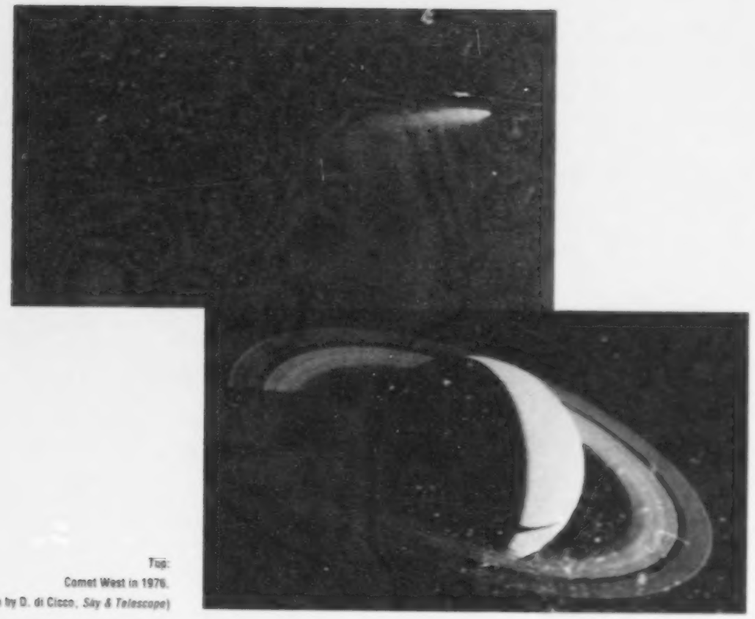


Top:
Comet West in 1976.
(Photo by D. di Cicco, *Sky & Telescope*)

Bottom:
Voyager 1's departing view of Saturn and its magnificent ring system.

Cover:
The CRAF spacecraft (top) as it orbits the nucleus of Comet Tempel 2. The Cassini spacecraft (bottom) soon after deploying the Huygens atmospheric entry probe toward Saturn's largest satellite, Titan.

INTRODUCTION

Two new journeys into outer space will soon offer a fresh perspective on the origin of the solar system — and perhaps provide new clues to the origin of life as well. Using a new generation of planetary exploration spacecraft, the first of these missions will venture to the outer solar system to study the rich diversity of the Saturn system, including the planet's rings and satellites, the surface and atmosphere of its principal moon, Titan, and the nature of fields and particles in Saturn's magnetosphere. A few months later, a nearly identical spacecraft will be launched to examine some of the most primitive bodies of the solar system: comets and asteroids. The National Aeronautics and Space Administration (NASA), in cooperation with the European Space Agency (ESA), the Deutsche Agentur für Raumfahrtangelegenheiten GmbH (DARA, the German Space Agency) and the Agenzia Spaziale Italiana (ASI, the Italian Space Agency), is preparing to embark on these two journeys in 1995 and 1996.

The missions are Cassini (the Saturn orbiter/Titan probe) and the Comet Rendezvous Asteroid Flyby (CRAF). They were proposed by the President and approved by the United States Congress in the NASA appropriation for Fiscal Year 1990. They are the first in a series of new planetary missions whose common objective is to explore primitive bodies and the outer solar system, with the ultimate goal of understanding the nature of our origin. To obtain the data needed to address that goal, the CRAF and Cassini missions carry many different scientific instruments that can be flown on spacecraft of the same basic design.

The planetary exploration programs of NASA and ESA have had an unparalleled record of success. The Viking landings on Mars, the Giotto flyby of Comet Halley and the Voyager flybys of the outer planets are examples of the outstanding record of exploration and scientific discovery compiled by both American and European planetary spacecraft. The record continues with the Magellan radar mapping of Venus, the Galileo spacecraft's journey toward arrival at Jupiter in 1995 and the Ulysses mission to fly over the Sun's poles in 1994 and 1995.

CRAF and Cassini are exciting planetary missions that continue this exploration into the 21st century. The pages that follow describe the objectives they share, the region of the solar system in which comets, asteroids and the Saturnian system have evolved and now reside, and the spacecraft that will carry both sets of experiments to their targets in the outer solar system.

The formation of planetesimals in the solar nebula. (Painting by William K. Hartmann)

Above:
Limb of Saturn's cloud-shrouded moon, Titan, showing its high-altitude layer of haze.

Facing page:
A region of active star formation in the Orion Nebula.

GOALS OF SOLAR SYSTEM EXPLORATION

Understanding the birth and evolution of our planetary system has been a goal of the United States civilian space program throughout the three decades of NASA's existence. In pursuit of this goal, NASA is guided by the Committee on Planetary and Lunar Exploration (COMPLEX) of the National Research Council, whose strategy for planetary exploration calls for a threefold progression — from reconnaissance (accomplished by fast flybys), through exploration (achieved by orbiters and probes), to intensive study (implemented by landers and sample-return missions). COMPLEX further recommends that this strategy be applied to each of the three regions of the solar system: the inner solar system (terrestrial planets), the primitive bodies (comets and asteroids) and the outer solar system (gas-giant planets and their moons).

The CRAF/Cassini Project represents NASA's latest application of this strategy to the primitive bodies and the outer solar system. Using a new generation of cost-effective, modular spacecraft that can be easily modified to accomplish a variety of missions to these targets, the program will focus on critical questions bearing on the origin and evolution of our planetary system. CRAF will fly by at least one large asteroid, orbit a comet and take a 25,000 to 50,000 kilometer journey down the comet's tail. Cassini will also fly by an asteroid, orbit the planet Saturn, fly repeatedly near several of Saturn's moons, and send an instrumented probe into the atmosphere of Saturn's moon Titan.

The explorations to be conducted by these two missions are complementary; their subjects — comets, asteroids, Titan and the Saturnian system — share a common origin in the outer solar system. These volatile-rich objects preserve unique records of different key phases in the formation and evolution of the solar system. They range from the most primitive conditions in interstellar clouds, through the chaotic and complex processes of nebular collapse and planetary formation (accretion), to the final sweep-up of interplanetary debris.

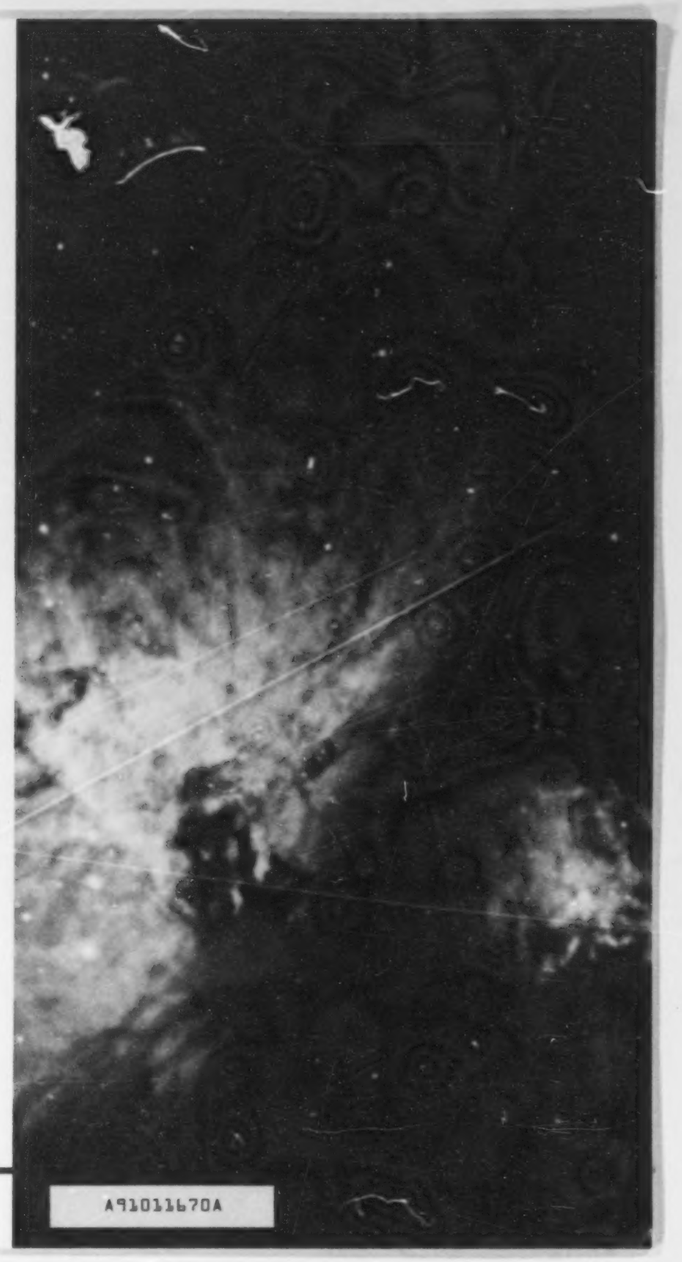
But this is more than a study of archaeological records. CRAF/Cassini will also investigate processes still taking place in these natural laboratories, processes that reproduce the physical and chemical effects that must have occurred in the primordial solar nebula and the environments around the forming planets.

There is the vast magnetosphere of Saturn, with its trapped ions, neutral gas and dust; the expanding cometary coma interacting with the supersonic solar wind; the complex and highly active ring system of Saturn, where local and distant gravitational fields are causing the collision and reorganization of dispersed matter; and the atmosphere of Titan, in which chemical reactions that may resemble the reactions that preceded the origin of life on Earth are taking place today. Similar interactions are believed to occur on still larger scales in stellar and galactic settings. The CRAF/Cassini measurements will help us to understand these astrophysical puzzles by providing in situ information on their analogs in our solar system.

PRIMITIVE BODIES AND THE OUTER SOLAR SYSTEM: CLUES TO ORIGIN AND EVOLUTION

Clues pertaining to the origin and evolution of the planets can be found throughout the solar system. During most of the 4.6 billion years since its origin, however, the solar system has been recovering from the violent and dynamic events from which it was created. On Earth and other terrestrial planets, virtually all evidence of the earliest evolutionary epochs has been obliterated by continuing modification of the planets' surfaces by internal and external processes. In contrast, comets, asteroids and the outer solar system have suffered fewer of these modifying effects and have thus retained some record of early planetary formation.

It is commonly believed that the terrestrial planets and the cores of the outer planets grew through the accretion of countless, small bodies called planetesimals, which were similar to present-day asteroids and comets. One group of these planetesimals has been preserved in the asteroid belt, a relatively stable region between the orbits of Mars and Jupiter. Disturbances by Jupiter's gravity probably prevented the asteroids from accreting into a single body of planetary size and thus they retain many of their primitive chemical and physical characteristics. One of the most scientifically interesting features of asteroids is their apparent diversity, and understanding the origin of that diversity requires the study of a large number of asteroids. The asteroid flyby investigations carried out by CRAF and Cassini will build on the information that the Galileo spacecraft will provide when it encounters two small asteroids en route to Jupiter.



May 1989
Magellan Launch

October 1989
Galileo Launch; CRAF/Cassini Project Start

February 1990
Galileo Venus Flyby

August 1990
Magellan Arrival at Venus

Above:
The nucleus of Comet Halley, as seen from the European Space Agency's Giotto spacecraft. (© Max-Planck-Institut für Aeronomie, 1986. Courtesy of Dr. H. U. Keller)

Facing page:
A Voyager view of Saturn's atmosphere and rings.

Just as asteroids and their meteoritic fragments may be samples of the building blocks of the inner solar system, comets appear to be icy remnants from the accretion of the outer planets. According to this view, the newly formed outer planets gravitationally scattered icy planetesimals, the comets, into distant orbits in the Oort cloud, which is the most remote region of the solar system and extends halfway to the nearest stars. There the comets remain, in the deep freeze of space, until a passing star, a giant molecular cloud or the tidal forces of the galaxy perturb them onto new paths that bring them back into the planetary region. An alternative scenario is that comets may be icy planetesimals that formed in the solar nebula beyond the orbit of Neptune and have been stored there ever since. In either case, comets have most likely been preserved in a condition similar to their initial state, relatively free from the modifying processes that occurred in larger bodies and in bodies closer to the Sun.

Because the giant planets of the outer solar system — Jupiter and Saturn in particular — are so massive, they have retained essentially all the material from which they were originally formed. Thus, these planets are expected to contain a representative sample of the original nebula, altered in chemical form, but retaining the elemental and isotopic signatures of the primordial solar nebula.

The rings around the outer planets permit the study of the dynamic interactions of small co-orbiting bodies, which are similar to the interactions among planetesimals that led to planetary accretion. The satellites of the outer planets are cold, frozen worlds that record an evolution that in some ways paralleled the evolution of the solar system as a whole. Ranging from the highly modified to the nearly pristine, these satellites have visible records of both external and internal processes frozen on their surfaces.

Another important goal of the CRAF/Cassini Project is to gather evidence concerning prebiotic molecular evolution in the solar system. The issue to be addressed involves how the chemical makeup of solar system material changed as the system evolved from interstellar cloud through solar nebula and finally to planetary formation to assume its present form. The molecular and mineralogical compositions of cometary material will yield information about the physical and chemical conditions and the earliest processes of change in the solar nebula. The dark material on comets, on carbonaceous asteroids and on the Saturnian moons Phoebe and Iapetus will yield information on the chemical changes caused by surface processes.

Scientists are especially intrigued by the possibility that prebiotic organic chemical evolution may have taken place in icy coatings on interstellar dust grains before those grains were incorporated into cometary nuclei; similar chemical evolution is still occurring on Titan. Both cometary ices and Titan's atmosphere contain many of the same organic molecules observed in interstellar clouds.

Recent research suggests that Earth's early atmosphere may have been inhospitable to the evolution of organic material and that the necessary, complex, prebiotic molecules may have been delivered to Earth from the outer solar system by comets and asteroids. An alternative theory is that the primitive terrestrial atmosphere may have been similar to Titan's present atmosphere. Thus, clues to understanding the origin of life on Earth may lie in the investigation of both the organic material frozen in comets and the present-day synthesis of organic compounds in Titan's atmosphere.

The CRAF/Cassini Project also seeks to enhance the understanding of a wide range of astrophysical processes by studying examples of those processes found within the solar system. One such example is to view Saturn's rings as a miniature analog of the collisional and accretional processes in the solar nebula. In a similar manner, studying the interaction of solar wind plasma with cometary gas and dust and of Saturn's magnetospheric plasma with its moons and rings will reveal the processes that heavily influenced the chemical and physical interactions in the solar nebula. Such processes must also be important in many other astrophysical settings in which gas, dust and plasma interact in the presence of ionizing radiation.

Spacecraft studies of the outer solar system will also yield information about solar system evolution and comparative planetology. The icy satellites extend the range of conditions and material properties of solid bodies that can be used for comparative studies of geological processes. The magnetospheres and atmospheres of giant planets such as Jupiter and Saturn, and the atmospheres and possible lakes of liquid hydrocarbons on Titan, provide points of comparison with the terrestrial planets.

The unifying theme for exploring primitive bodies and the outer planets is the study of the origin and evolution of the solar system; this study includes the analysis of the prebiotic organic chemistry found in this frozen, volatile-rich part of the solar system.

October 1990
Ulysses Launch

December 1990
Galileo: First Earth Flyby

May 1991
Magellan: Extended Mission Begins

October 1991
Galileo: Gaspra Asteroid Flyby

Above:
Comet Bennett, photographed over the Alps in 1970. (Photo by C. Nicollier)

COMET RENDEZVOUS ASTEROID FLYBY

During its nine-year journey, CRAF will explore a comet and at least one asteroid. To learn how comets were formed and how they come apart under the influence of sunlight, CRAF will fly along with a typical short-period comet as it moves around the Sun. The mission will determine the elemental, isotopic, molecular and mineralogical compositions of cometary material and will investigate the large-scale physical structure of the nucleus. Furthermore, CRAF will study the physics and chemistry of the comet's atmosphere as well as its interaction with sunlight and the solar wind. Finally, CRAF will survey the physical properties of a large asteroid, including its size, shape, rotation period, pole orientation and surface morphology; it will also gather preliminary information about the asteroid's chemical composition and measure its mass and bulk density.

The space missions to Comet Halley in 1986 provided the first quick glimpse of a comet nucleus and the first in situ measurements of cometary gas and dust. In many respects, however, the Halley flybys raised more questions than they answered. While they showed, for example, that comets contain a large amount of organic material, they were unable to determine precisely which organic molecules were present. The flybys also revealed that the nucleus of a comet is a dark, irregularly shaped body, but they could not determine its density, the physical cause(s) of its irregular shape or the composition of its dark, presumably organic surface material.

The rendezvous mission designed for CRAF represents a substantial advance beyond the ultrafast Halley flybys. In a rendezvous mission, a spacecraft follows an orbit around the Sun that precisely matches the comet's orbit. Hence, after a rendezvous maneuver, the spacecraft and the comet travel together indefinitely. Among the many significant advantages of a rendezvous mission over a flyby are the ability to obtain more detailed maps (the spacecraft can move completely around the nucleus at will, studying the nucleus from every angle), the longer observation times and lower relative speeds (time-variable phenomena can be studied, and dust and gas samples can be collected without vaporizing them first), and the capacity for adaptive exploration (the science teams can respond to an interesting result by making additional observations).

The target for CRAF's rendezvous is the short-period comet Tempel 2, which circles the Sun every 5.4 years. Tempel 2 has an eccentric orbit that passes inside the orbit of Mars and extends outward almost as far as the orbit of Jupiter. Discovered in 1873 at Milan Observatory by astronomer Ernst Wilhelm Tempel, the comet has been observed on 18 appearances and is one of the most active and best studied short-period comets in the solar system.

To reach Comet Tempel 2, the spacecraft will launch on a trajectory that swings twice by Venus and once by Earth for gravity assists that will then fling it out well beyond the orbit of Mars. Like the Galileo mission, which has already used these two planets for gravity assists on its way to Jupiter, CRAF will conduct valuable scientific observations during the flybys, adding to the total return from the CRAF mission and providing useful tests of the spacecraft's components and ground operations system. Between the second Venus flyby and the Earth flyby, the spacecraft will encounter the primitive main-belt asteroid 739 Mandeville, which has a diameter of 110 kilometers and a surface composition believed to be similar to that of carbonaceous chondrite meteorites. Mandeville, which was discovered in 1913 by the Rev. Joel Metcalf at Winchester, Massachusetts, is named for the city of Mandeville on the island of Jamaica.

February 1992
Ulysses: Jupiter Flyby

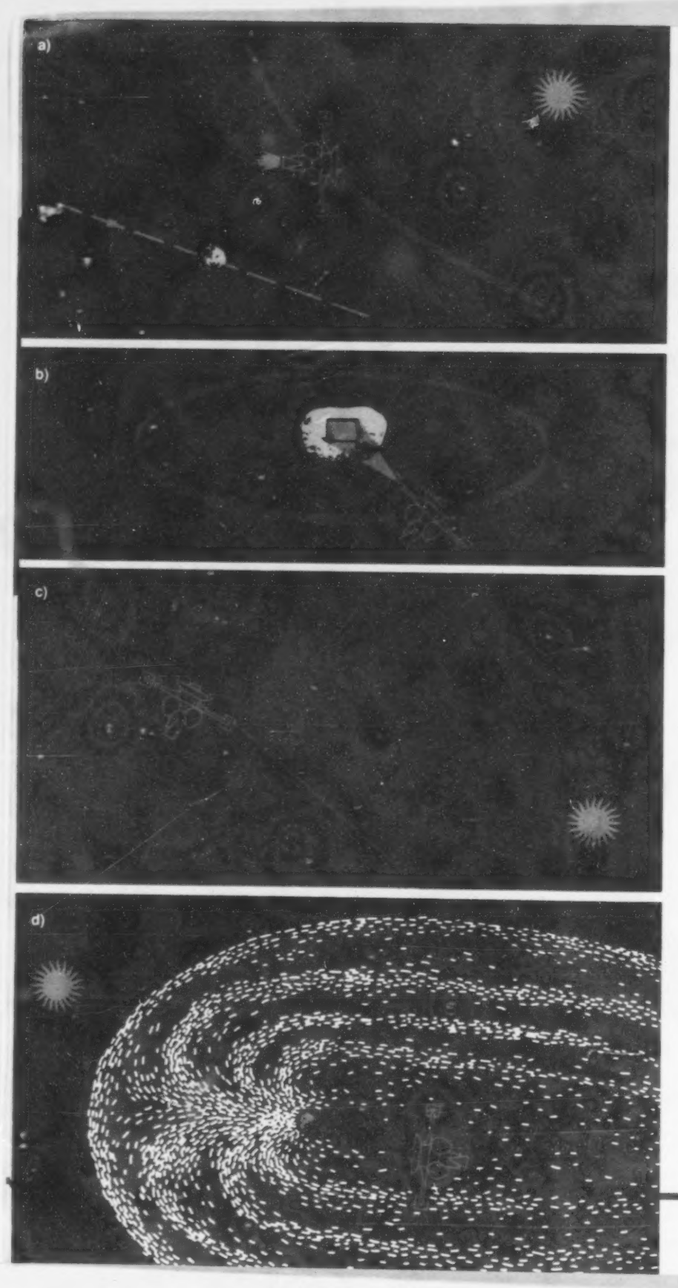
September 1992
Mars Observer Launch

December 1992
Galileo: Second Earth Flyby

August 1993
Mars Observer: Arrival at Mars

August 1993
Galileo: Ida Asteroid Flyby

August 1994
Ulysses: Over Sun's South Pole

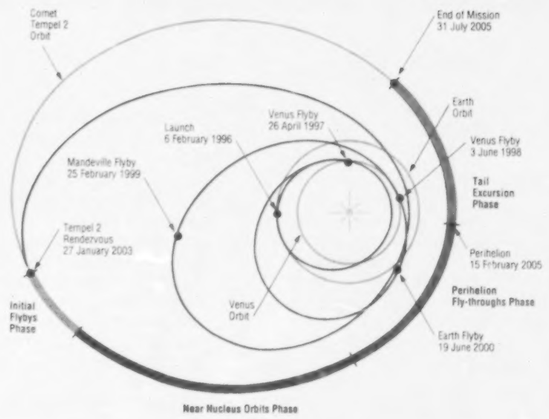


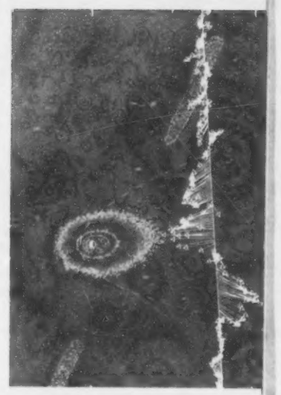
CRAF will arrive at Comet Tempel 2 near aphelion, at a solar distance of 4.5 astronomical units, where the comet is relatively inactive. Beginning with a series of slow, ever closer flybys, the spacecraft will be placed in orbit around the comet nucleus about five months after arrival. From a distance of 50 to 100 kilometers, the spacecraft will use remote sensing instruments to study the comet. Images with a resolution of better than one meter will provide details about the size, shape and surface morphology of the comet nucleus. Analyzing the spectrum of reflected sunlight will allow the identification of ices and minerals on the comet's surface. Temperature will be mapped to determine thermal properties and energy balance, and to aid in the identification of surface materials. Accurate radio tracking data will be used to determine the mass of the cometary nucleus. Combined with the size, as estimated from the pictures, this information will make possible the calculation of the comet's bulk density. Taken together, these measurements will enable scientists to establish whether the interior of a comet nucleus more closely resembles a hardpacked snowball, a newly fallen fluffy bank of snow, or an agglomeration of chunks of material held together by ice and organic "glue." This new information will reveal how the comet nucleus accreted and what modifying processes it might have undergone since its formation.

As the comet nears the Sun and becomes more active, the spacecraft will leave its fixed orbit and move in and out through Comet Tempel 2's atmosphere, collecting dust for onboard analysis of the elemental, chemical and molecular properties of the microscopic grains. Emitted gases will be analyzed for their composition and temperature, and for the velocity at which they flow outward from the nucleus. This study of the cometary atmosphere and nucleus will continue as Comet Tempel 2 moves along its eccentric orbit and reaches maximum activity shortly after perihelion.

A complete set of plasma instruments will study interactions of cometary gas and dust with sunlight and with the solar wind in efforts to clarify what takes place during the formation and constant changing of shapes of comet tails, the acceleration of energetic particles, and other plasma processes.

Following perihelion, CRAF will take a 25,000 to 50,000 kilometer excursion down the comet's tail to explore the comet-solar wind interaction in further detail. After the tail excursion, the CRAF spacecraft will return to the vicinity of the Tempel 2 nucleus as the comet's activity wanes. As the comet once again begins to journey outward from the Sun, CRAF will conclude the mission by returning to close orbit around the nucleus and studying the changes that the nucleus has undergone during perihelion. The spacecraft will be maneuvered ever closer to the nucleus, allowing high resolution observations not possible earlier in the mission, until its fuel is exhausted and it impacts gently on the nucleus surface.

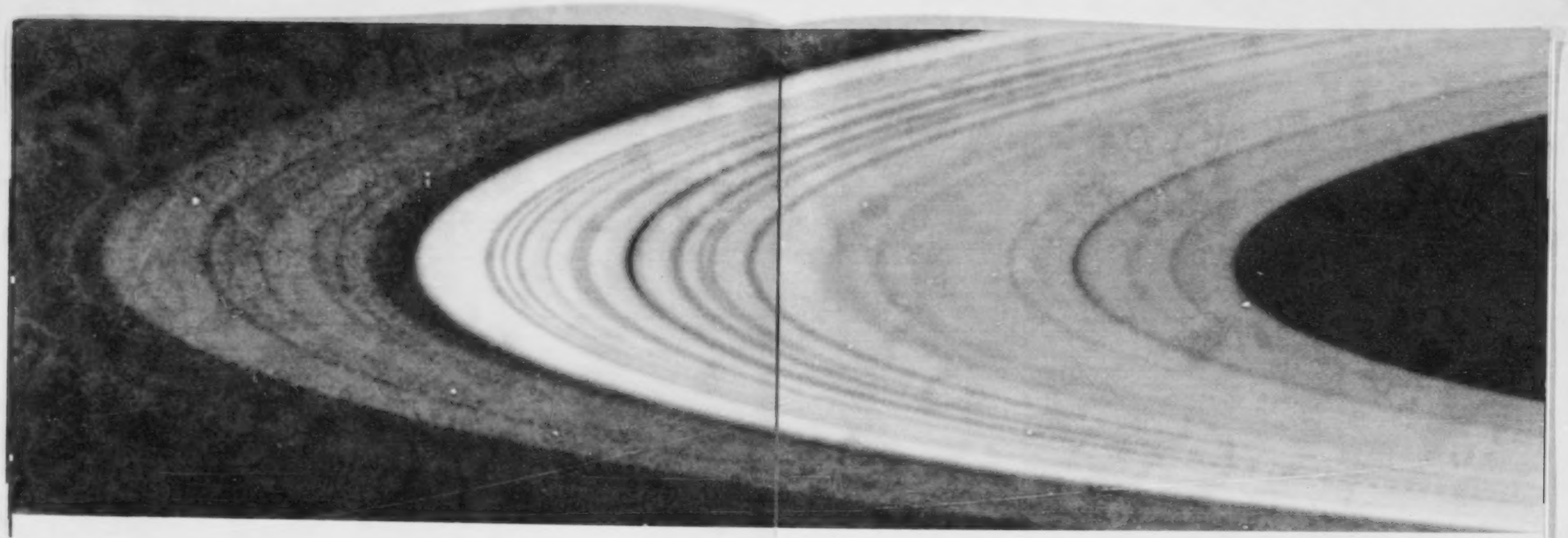

Comet Tempel 2 Orbit
End of Mission 31 July 2005
Earth Orbit
Venus Flyby 3 June 1998
Tail Excursion Phase
Perihelion 15 February 2005
Perihelion Fly-throughs Phase
Earth Flyby 19 June 2000
Launch 6 February 1996
Venus Flyby 26 April 1997
Mandeville Flyby 25 February 1999
Tempel 2 Rendezvous 27 January 2003
Initial Flybys Phase
Venus Orbit
Near Nucleus Orbits Phase



Above:
Magnetic field vectors, measured by the International Cometary Explorer spacecraft in the tail of Comet Giacobini–Zinner, are superimposed on an image of the comet obtained at the Canada–France–Hawaii telescope on Mauna Kea.
(Courtesy of B. Goldberg & J. A. Slavin)

Left:
The interplanetary trajectory and mission phases of CRAF.

Facing page:
The major phases of the CRAF mission:
(a) Matching orbits or "rendezvousing" with Comet Tempel 2 far from the Sun.
(b) Close orbit around the nucleus.
(c) Repeated fly-throughs of the active cometary atmosphere.
(d) The 25,000 to 50,000 kilometer tail excursion, after perihelion.



Above:
Saturn's rings,
as photographed by Voyager 1.

Facing page:
The interplanetary trajectory
of the Cassini spacecraft.

CASSINI

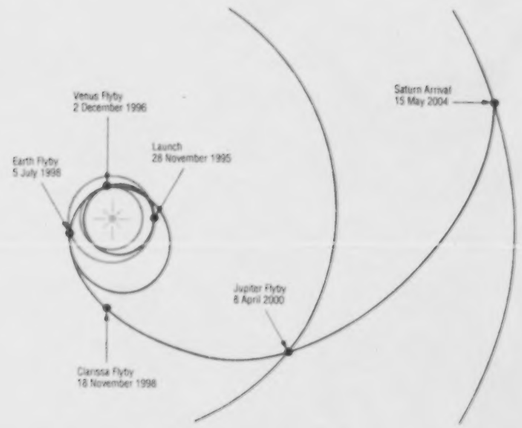
The Cassini mission is named for Jean Dominique Cassini (1625–1712), the first director of the Paris Observatory, who discovered several of Saturn's satellites and the major division in its rings. The Titan atmospheric entry probe is named for the Dutch physicist Christiaan Huygens (1629–1695), who discovered Titan and first described the true nature of Saturn's rings.

Cassini will explore the Saturnian system, which contains a host of volatile-rich bodies and a record of the processes that have modified them. The mission will be composed of a Saturn orbiter spacecraft built by NASA and a detachable Titan entry probe supplied by ESA. The Saturn orbiter will deliver the Huygens probe to Titan and, on each orbit of Saturn, will make a close flyby of Titan to allow intensive study of this most unusual moon.

One of the most intriguing aspects of Titan is the possibility that its surface may be covered in part with lakes of liquid hydrocarbons that result from photochemical processes in its upper atmosphere. These hydrocarbons condense to form a global smog layer and eventually rain down onto the surface. The Cassini orbiter will use onboard radar to peer through Titan's clouds and determine if there is liquid on the surface. Experiments aboard both the orbiter and the entry probe will investigate the chemical processes that produce this unique atmosphere.

As the Huygens probe enters Titan's atmosphere, it will begin taking measurements in the haze layer above the cloud tops. The probe will carry a well-equipped robotic laboratory with which to make chemical analyses of Titan's atmosphere and clouds. As the probe descends, first on a parachute and later in free fall, other instruments will measure the temperature, pressure, density and energy balance in the atmosphere, all the way to the surface. Properties of the surface will be measured remotely, and a camera will take pictures of the Titan panorama as the probe breaks through the cloud deck. If the probe survives the landing, it will relay measurements from the surface before the orbiter flies beyond the horizon and out of radio contact.

The orbiter's radar will take pictures of Titan's surface through the clouds, just as the Magellan spacecraft has done at Venus. A large fraction of the surface will be mapped to



February 1998
CRAF Launch

June 1998
Galileo: First Ganymede Flyby

December 1998
Cassini: Venus Flyby

October 1997
Galileo: Nominal Mission Ends

April 1997
CRAF: First Venus Flyby

June 1998
CRAF: Second Venus Flyby

a resolution of several kilometers, some portions will be mapped at 300-meter resolution. The orbiter will also carry remote sensing instruments to measure the composition and structure of Titan's atmosphere on a global scale. It will come so close to Titan on many passes that it will actually fly through the upper atmosphere. At those times, several aeronomy instruments will make in situ measurements of atmospheric composition.

Another of Saturn's moons, Iapetus, has one hemisphere that is six times darker than the other; many scientists suspect that this very dark material is organic in nature. How this particular moon, with its dark material and its strange hemispheric asymmetry, came to be among all the other very bright, icy moons in the Saturnian system remains a mystery. Cassini will examine the dark material on Iapetus to determine the dark material's relationship, both to organic material in Titan's atmosphere and to dark material on comets, asteroids and the dark moons of Mars, Phobos and Deimos.

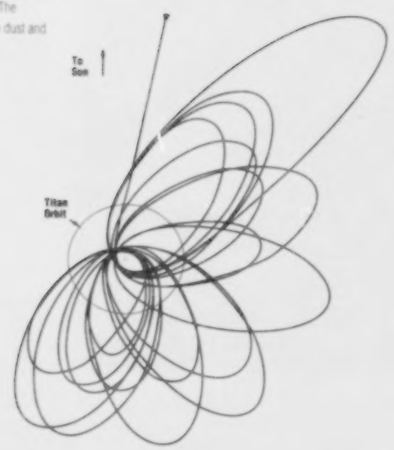
The orbiter will also pass within a few hundred kilometers of several of Saturn's other moons. Cameras will take pictures of the intensely cratered surfaces of these icy moons, radar will map their topography, spectroscopic instruments will determine the compositions of their surfaces, and plasma instruments will observe their interaction with the Saturn magnetosphere.

Besides the large moons, Saturn's equatorial plane contains many smaller objects and considerable dust; it also includes the magnificent ring system close to the planet. Cassini will examine in detail these dynamic and enigmatic rings, which were explored only briefly by earlier flybys. No other planet in the solar system contains as much orbital debris as Saturn, where several moons occupy virtually the same orbit. Cassini will survey the small bodies orbiting Saturn and will search for moonlets within the rings. The mission will also study the physical properties of the ring particles in fine detail to unravel the mysteries of their structure, dynamics, composition and formation.

The structure and composition of Saturn's atmosphere will also be examined. Sensitive instruments on the Cassini orbiter will make remote chemical and physical measurements deep in the atmosphere of Saturn. The information thus derived will be compared with the Jupiter data obtained by the Galileo mission. The resulting comparative studies of these two giant planets will contribute far more to our understanding of planetary origin and evolution than could be gained through the study of either planet alone.

The interactions of Saturn's magnetosphere with the rings and with Titan's atmosphere are the most complex examples of these types of phenomena in the solar system. The magnetospheric interactions with dust and moonlets in the ring plane provide information about some of the processes involving the interactions of plasma, dust and radiation that were important at the beginning of the solar system when the planets were formed.

Finally, one of the benefits of Cassini's trajectory from Earth to Saturn is a passage close to Jupiter. The trajectory also includes gravity assist flybys of Venus and Earth and a flyby of a large, main-belt asteroid. The Cassini flyby of Jupiter, which will provide new observations of the Jovian system by instruments more advanced than those carried on Galileo, will extend the time base of Galileo's earlier observations and measurements. The combined asteroid flyby data from Galileo, CRAF and Cassini will provide a data set on several different members of this very diverse class of solar system objects, as well as their relationship to other small bodies such as comets and larger bodies like moons and the terrestrial planets.



Above:
Saturn's moon Enceladus, with its plains and heavily cratered terrain.

Left:
The Cassini trajectory after arrival at Saturn, passing Titan on each orbit.

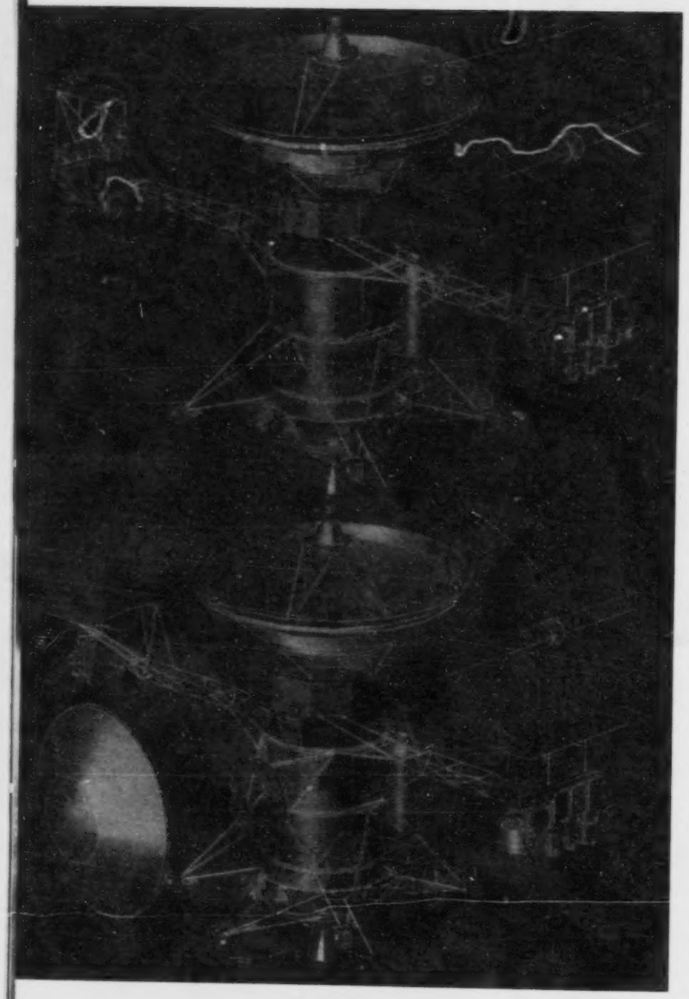
Facing page:
An artist's concept of Saturn and the Cassini spacecraft (background), with the ESA probe on its way into the atmosphere of Titan.

July 1998
Cassini: Earth Flyby

November 1999
Cassini: Asteroid Clarissa Flyby

February 1999
CRAF: Asteroid Mandeville Flyby

April 2000
Cassini: Jupiter Flyby



THE MARINER MARK II SPACECRAFT

The Mariner Mark II spacecraft is designed specifically to carry out deep space missions to comets, asteroids and the outer planets. The spacecraft will therefore be equipped to meet a multiplicity of demands imposed by the nature of these missions: providing electrical power at great distances from the Sun, transmitting large amounts of data to Earth over these vast distances, providing highly accurate pointing for the precise aiming of remote sensing instruments and/or delivery of entry probes, and properly orienting the communications antennas. Of equal significance is the need for a high degree of autonomous operation and reliability.

At the same time, the cost of the missions must be minimized without compromising quality. The Mariner Mark II spacecraft will meet this challenge by maintaining a configuration for its various missions that is as nearly uniform in design as possible. For CRAF and Cassini, each spacecraft will be designed to carry either set of instruments, power them, point them, and store and transmit their data with the fewest possible changes in spacecraft design. Where detailed requirements differ, the final design is driven by the requirements of the more demanding mission. The size of the propellant tanks, for example, is determined by CRAF's requirements. Cassini will use the same tanks, but they will not be completely filled with fuel. Conversely, the size of the high-gain antenna is defined by the distance between Saturn and Earth, a Cassini requirement. The same antenna is used for the CRAF mission, even though a smaller one would suffice. The cost of over-designing for the mission with the less stringent requirements is more than compensated for by savings derived from the design, construction, testing and operation of identical subsystems on both missions.

This philosophy has even been extended to the scientific instruments where possible. CRAF and Cassini will carry identical narrow- and wide-angle charge-coupled device (CCD) cameras, visible and infrared mapping spectrometers, neutral gas and ion mass spectrometers, plasma spectrometers and magnetometer experiments. The scientific teams who will use these instruments are chosen separately for each mission.

Computer generated drawings show the two spacecraft complete with their scientific instruments. The principal common features are the central, 12-sided spacecraft bus that holds most of the electronics, the large propulsion subsystem (fuel tanks and rocket engine) contained in a cylindrical housing below the bus, the 4-meter diameter high-gain antenna and radio feeds above the bus, the three nuclear-powered radioisotope thermoelectric generators mounted at the base of the cylindrical housing, and the booms on which experiments are mounted. For Cassini, the ESA-provided Huygens entry probe is shown in front of its mounting location on the spacecraft.

The two spacecraft will fly with their high-gain antennas pointed towards Earth. On CRAF, two instrument-laden platforms will keep the telescopes and other sensors trained on the target under study. The Cassini cameras and spectrometers will use a platform identical to that for CRAF. The other Cassini instrument platform is a turntable that will rotate continuously, creating ever-changing maps of the dust, plasma and energetic particles arriving from all parts of the Saturn magnetosphere.

Both spacecraft are being designed and built by NASA, the Titan Huygens probe by ESA, the high-gain antennas by Italy, and the propulsion subsystem by Germany. Scientific instruments will be provided by all of the international partners. Both the CRAF and Cassini missions will be launched from Cape Canaveral on the expendable Titan IV/Centaur launch vehicle: Cassini in late 1995 and CRAF in early 1996.

Above:
A mosaic of Viking images of the Martian moon Phobos, which may be a captured asteroid.

Facing page:
Computer-aided design drawings of the CRAF (top) and Cassini spacecraft. The Huygens entry probe is shown in front of its mounting location on the Cassini orbiter.

June 2000
CRAF: Earth Flyby

January 2003
CRAF: Arrival at Comet Tempel 2

May 2004
Cassini: Arrival at Saturn

September 2004
Cassini: Huygens Probe Enters Titan Atmosphere

February 2005
CRAF: Comet Tempel 2 at Perihelion

July 2005
CRAF: Nominal Mission Ends

May 2007
Cassini: High Inclination Orbits

SUMMARY

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Above:
An artist's view of the solar nebula before the planets formed.
(Painting by Don Davis.
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The knowledge from the CRAF/Cassini missions will greatly enhance what has already been discovered about the outer solar system through ground-based observations and through previous missions: Pioneers 10 and 11 and the Voyager 1 and 2 encounters of Jupiter, Saturn, Uranus and Neptune. CRAF will help to explain the intriguing glimpses into the mysteries of a comet nucleus that were first offered by the international flotilla of spacecraft that flew by Comet Halley in 1986 and the International Cometary Explorer fly-through of the tail of Comet Giacobini–Zinner in 1985. Cassini will provide a thorough investigation of the Saturnian system and will complement the Galileo investigation of Jupiter.

With the implementation of the CRAF and Cassini missions, NASA will fulfill a substantial part of the United States' commitment to the exploration of the solar system. There will be orbiters at Venus (Magellan), Mars (Mars Observer), Jupiter (Galileo), Saturn (Cassini) and a comet (CRAF). Probes will have been delivered into the atmospheres of Venus (Pioneer Venus), Jupiter (Galileo) and Titan (Cassini). In addition, Galileo, CRAF and Cassini will have begun the reconnaissance of asteroids, with flybys of several asteroids of different compositional types and sizes.

To accomplish these missions, an exceptional spacecraft has been designed that can accommodate a wide variety of targets and scientific instruments with only minor modifications in spacecraft design from one mission to the next. Future Mariner Mark II missions are now under study for a Neptune orbiter and entry probe, and for a Pluto flyby mission. Other Mariner Mark II spacecraft may return a sample from a cometary nucleus, or orbit one or more main belt asteroids and study them with the same intensity as CRAF and Cassini will study their targets. Endless possibilities exist to satisfy our need for knowledge and understanding and to unravel the clues, hidden for billions of years, that the outer solar system holds to the mysteries of our origin and evolution.

May 2008
Cassini: Nominal Mission Ends

COMET RENDEZVOUS ASTEROID FLYBY — SCIENCE PAYLOAD

Instrument	Principal Investigator/Team Leader	Institution
Imaging Science (facility)	Joseph Veverka	Cornell University
Visual and Infrared Mapping Spectrometer (facility)	Thomas B. McCord	University of Hawaii
Comet Dust Environment Monitor	W. Merle Alexander	Baylor University
Suprathermal Plasma Investigation of Cometary Environments	James L. Burch	Southwest Research Institute
Cometary Ice and Dust Experiment	Glenn C. Carle	NASA Ames Research Center
Cometary Matter Analyzer	Jochen Kissel	Max-Planck-Institut für Kernphysik
Cometary Retarding Ion Mass Spectrometer	Thomas E. Moore	NASA Marshall Space Flight Center
Neutral Gas and Ion Mass Spectrometer	Hasso B. Niemann	NASA Goddard Space Flight Center
Coordinated Radio, Electron and Wave Experiment	Jack D. Scudder	NASA Goddard Space Flight Center
Magnetometer	Bruce T. Tsurutani	Jet Propulsion Laboratory
Thermal Infrared Experiment	Francisco P. J. Valero	NASA Ames Research Center
Radio Science (facility)	Don Yeomans	Jet Propulsion Laboratory
Interdisciplinary Scientists		
Active Nucleus	Armand Delsemme	University of Toledo
Asteroid and Inactive Nucleus	David Morrison	NASA Ames Research Center
Coma	Walter F. Huebner	Southwest Research Institute
Solar Wind Interaction	D. Asoka Mendis	University of California, San Diego
Exobiology	Christopher P. McKay	NASA Ames Research Center

CASSINI SATURN ORBITER — SELECTED PAYLOAD

Instrument	Principal Investigator/Team Leader	Institution
Imaging Science (facility)	Carolyn C. Porco	University of Arizona
Visual and Infrared Mapping Spectrometer (facility)	Robert H. Brown	Jet Propulsion Laboratory
Cassini Radar (facility)	Charles Elachi	Jet Propulsion Laboratory
Ion and Neutral Mass Spectrometer (facility)	(To be Selected)	(To be Determined)
Ultraviolet Imaging Spectrometer	Larry Esposito	University of Colorado
Cosmic Dust Analyzer	Eberhard Grün	Max-Planck-Institut für Kernphysik
Radio and Plasma Wave Subsystem	Donald Gurnett	University of Iowa
Magnetospheric Imaging Instrument	Stamatios Krimigis	Johns Hopkins University
Composite Infrared Spectrometer	Virgil Kunde	NASA Goddard Space Flight Center
Dual Technique Magnetometer	David J. Southwood	Imperial College, London
Cassini Plasma Spectrometer	David T. Young	Southwest Research Institute
Radio Science (facility)	Arvydas Kliore	Jet Propulsion Laboratory
Interdisciplinary Scientists		
Magnetosphere and Plasma	Michel Blanc	Observatoire Midi-Pyrenees
Rings and Dust	Jeff Cuzzi	NASA Ames Research Center
Magnetosphere and Plasma	Tamas Gombosi	University of Michigan
Atmospheres	Tobias Owen	University of Hawaii
Origin and Evolution	James B. Pollack	NASA Ames Research Center
Satellites and Asteroids	Laurence Soderblom	U.S. Geological Survey
Aeronomy and Solar Wind	Darrell F. Strobel	Johns Hopkins University

CASSINI HUYGENS PROBE — SELECTED PAYLOAD

Instrument	Principal Investigator/Team Leader	Institution
Doppler Wind Experiment	Michael K. Bird	Universität Bonn
Atmospheric Structure Instrument	Marcello Fulchignoni	Università di Roma "La Sapienza"
Aerosol Collector and Pyrolyser	Guy M. Israel	Service d'Aeronomie du CNRS
Gas Chromatograph/Mass Spectrometer	Hasso B. Niemann	NASA Goddard Space Flight Center
Descent Imager/Spectral Radiometer	Martin G. Tomasko	University of Arizona
Surface Science Package	John C. Zarnecki	University of Kent
Interdisciplinary Scientists		
Titan Aeronomy	Daniel Gautier	Observatoire de Paris-Meudon
Titan Atmosphere/Surface Interactions	Jonathan Lunine	University of Arizona
Organic Chemistry	François Raulin	Universite de Paris-Val de Marne

NASA
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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